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THE DISSECTED VOLCANO OF CRANDALL BASIN, WYOMING.*

THE writer in exploring the north-eastern corner of the Yellowstone National Park and the country east of it came upon evidences of a great volcano, which had been eroded in such a manner as to expose the geological structure of its basal portion.

The work was carried on as a part of the survey of this region, under the charge of Mr. Arnold Hague of the U. S. Geological Survey. The paper is an extract from a chapter in the final report on the Yellowstone National Park in process of completion, and the writer is indebted to Major J. W. Powell, Director of the Survey, and to Mr. Hague, chief of the division, for permission to present it at this time in anticipation of the publication of the final report.

The area of volcanic rocks described is but a small portion of the great belt of igneous material that forms the mountains of the Absaroka range, lying along the eastern margin of the Yellowstone Park.

The volcano of Crandall Basin is one of a chain of volcanic centers situated along the northern and eastern border of the Yellowstone Park, which are all distinguished by a greater or less development of radiating dikes, and by a crystalline core eroded to a variable extent.

The Palæozoic and Mesozoic strata, which formed an almost continuous series to the coal-bearing Laramie, had been greatly disturbed and almost completely eroded in places before the volcanic ejectamenta in this vicinity were thrown upon them. The period of their eruption is, therefore, post-Laramie, presumably early Tertiary.

The first eruptions of andesite were followed by those of basalt in great amounts, and these by others of andesite and basalt like the first. This was succeeded by a period of extensive erosion ; reducing the country to nearly its present form. Then came the eruption of a vast flood of rhyolite constituting the Park plateau, which was followed in this region by smaller outbreaks of basalt. The last phase of volcanic activity is found in the geysers and fumaroles which have rendered this region famous.

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*Abstract of a paper read before the British Association for the Advancement of Science, September, 1893.

The volcano of Crandall Basin consists chiefly of the first series of basic andesites and basalts. The earlier acidic andesite, which occurs beneath these rocks, appears to be the remnants of eruptions from neighboring centers.

Nothing remains of the original outline of the volcano. The district is now covered by systems of valleys and ridges of mountain peaks that rise from two thousand to five thousand feet above the valley bottoms. The geological structure of the country, however, makes its original character evident.

The outlying portions of the district to the south, west, and north consist of nearly horizontally bedded tuffs, and subaërial breccias of basic andesite and basalt. With these are intercalated some massive lava flows, which are scarce in the lower parts of the breccia, but predominate in the highest parts, above an altitude of ten thousand feet. Here they constitute the summits of the highest peaks.

In contrast to the well-bedded breccias around the margin of the district, the central portion consists of chaotic and orderless accumulations of scoriaceous breccia with some massive flows. These breccias carry larger fragments of rocks and exhibit greater uniformity in petrographical character.

A still more noticeable feature of the central portion of the district is the occurrence of dikes which form prominent walls, and may be traced for long distances across the country. The greater part of them are found to converge toward a center in the highest ridge in the middle of the drainage basin of Crandall creek. A small number converge toward a second center three or four miles east of the first. In the southern part of the district there are many dikes trending toward a center near the head of Sunlight Basin, about fifteen miles south of the Crandall center.

The center toward which the Crandall dikes converge is a large body of granular gabbro, grading into diorite. It is about a mile wide, and consists of numerous intrusions penetrating one another and extending out into the surrounding breccia, which is highly indurated and metamorphosed in the immediate vicinity of the core. Within the area of indurated breccia the dike rocks become coarse grained rapidly as they approach the gabbro core. This was undoubtedly the central conduit of an ancient volcano, the upper portion of which has been eroded away.

Upon comparing the geological structure of this region with that of an active volcano, like Etna, it is apparent that the lava flows which form the summits of the outlying peaks must have been derived from lateral cones fed by dikes radiating from the central conduit. And assuming that the volcano of Crandall Basin was similar in type to that of Etna, an idea of its original proportions is derived by constructing upon profile sections through the Crandall cone the outline of Etna. If the erosion of the summits of the highest peaks is neglected, the resulting height of the ancient volcano above the limestone floor is estimated at about thirteen thousand four hundred feet. This is undoubtedly too low, and is well within the limits of present active volcanoes. Erosion has removed at least ten thousand feet from the summit of the mountain to the top of the high central ridge in which the granular core is situated, and has cut four thousand feet deeper into the valleys on either side. It has prepared for study a dissected volcano, which, it is hoped, will in time reveal some of the obscurer relationships existing between various phases of igneous rocks.

Petrological Features.—It will not be possible in an abstract to do more than present, in the briefest manner, the more salient features of the petrology of the rocks of this volcano. The rocks are mostly the same as those in various parts of the Yellowstone National Park, some of which have been described in another place. The older acidic breccia consists of fragments and dust of hornblende-mica-andesite, hornblende-andesite, and hornblende-pyroxene-andesite. They are partly glassy and partly holocrystalline. In some places they appear to pass into the overlying breccia, but in others they have been eroded and weathered before the latter were thrown over them.

The upper breccia, which constitutes the main mass of the volcano, is basaltic as a whole. It consists of pyroxene-andesite and basalt, the latter predominating in the upper part of the accumulation. The massive flows, as far as investigated, are all basalt. The composition varies constantly within narrow limits. A greater part of these rocks contain glassy groundmass.

The rocks constituting the dikes exhibit more variation than the breccias, though the majority of them are like the breccias in composition and habit, being basalt. They are generally more crystalline. A great many dike rocks resemble the basalts in outward appearance, but have little or no olivine, and are more crystalline. The absence of olivine from the more crystalline forms of these rocks appears to be due to the conditions which influenced the crystallization of the rocks and not to their chemical composition. For in some cases what appear in hand specimens to be decomposed olivines are found to be paramorphs after this mineral, consisting of grains of augite, magnetite, and biotite. As the rocks become more crystalline biotite becomes an essential constituent; the porphyritical minerals lose their sharpness of outline and assume some of the microscopical characteristics which they possess in gabbro.

Within the core the coarest grained forms are gabbro. The composition varies in different parts of one continuous rock mass, and also between different intrusions within the core. The transition is from gabbro to diorite with biotite and quartz; and the extreme variety is that form of granite called aplite; the range in silica being from 51.81 to 71.62 per cent.

Fine grained, andesitic equivalents of diorite occur in dikes outside of the core, but none of the most silicious varieties have been found outside of it. From this it appears that toward the end of volcanic activity near the core the composition of the magmas became more and more silicious, and the volume of the lava erupted smaller. But this change in composition was not uninterrupted, for there are evidences of the alternate eruption of basic magmas as well. Dikes of more silicious rocks are traversed by later dikes of basic rocks. This has taken place both within and outside of the core. Some of these basic rocks are uncommonly low in silica for rocks of this region. They are all found at some distance from the core, with one exception, which is an intrusion within the core. They are lamprophyric in the sense used by Professor Rosenbusch, and approach more or less closely typical camptonites, monchiquites, kersantites, and minettes. They are connected with the basalts of the district by mineralogical and structural transitions.

These exceptionally basic rocks are the chemical complements of the acidic ones in the core and appear to be among the latest extrusions. While they agree with one another in having a low percentage of silica, they differ in the relative abundance of magnesia, lime and iron oxide on the one hand, and of alumina, soda and potash on the other.

As already pointed out by the writer in another place, the variability in composition of all of the volcanic rocks in this volcano illustrates one mode of differentiation of a magma at a particular center of eruption. A comparison of the chemical and mineral composition of the rocks of this district furnishes additinal evidence of the fact that magmas which are chemically similar will crystallize into different groups of minerals according to the conditions through which they pass. Thus chemically similar magmas may form basalt under one set of conditions, and gabbro under others; the first composed of plagioclase, augite, olivine, magnetite and sometimes hypersthene; the second consisting of plagioclase, augite, hypersthene and biotite, besides some magnetite, orthoclase and quartz, with or without hornblende.

Minerals, then, which are primarily functions of the chemical composition of rocks are also functions of the physical conditions affecting crystallization. Some of the conditions under which the molten magmas solidified within the dikes and core of the volcano of Crandall basin, may be inferred from a consideration of the geological structure of this ancient volcano. The magmas which solidified within that portion of the core now exposed, and those in dikes within a radius of two miles, must have occupied positions at nearly the same distance beneath the surface of the volcano, that is, at a depth of about 10,000 feet and over. The one was as deep-seated or abysmal as the other, and yet their degrees of crystallization range from glassy to coarsely granular.

The influence of pressure on the crystallization is not recognizable either in the size of grain or the phase of crystallization. Marked changes in the crystallization may be traced horizontally in the immediate vicinity of the core. They are rapid near the core, and are accompanied by the induration and metamorphism of the surrounding rocks. They are in a general measure independent of the size of the rock-body, since narrow dikes within the core are coasely crystalline, while much broader ones in the surrounding breccias are very fine grained. It was, unquestionably, the differences in the temperature of the core rocks and of the outlying breccias which affected the degree of crystallization. The former must have been more highly heated than the latter rocks, and the magmas solidifying within them cooled much slower than those injected into the outlying parts of the volcano. In this case the depth at which the magmas solidified appears to have been of little moment in comparison with the temperature of the rocks by which they were surrounded.

The core of gabbro and diorite with an intricate system of veins of middle grained porphyritic rocks, and radiating dikes of aphanitic and glassy lavas, encased in an accumulation of tuffs and breccias with flows of massive lava, constitute an extinct or completed volcano. The central core consists of the magmas that closed the conduit through which many of the eruptions had reached the surface. In solidifying they became coarse grained. The question naturally suggests itself, Are these coarse grained rocks any less volcanic than those that reached the surface? What part of a volcano is non-volcanic?

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